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The nitrogen : phosphorus relationship in lakes

John A. Downing
Département de Sciences biologiques, Université de Montréal, C.P. 6128, Succursale A, Montréal, Québec H3C 3J7

Edward McCauley
Ecology Division (Aquatic Group), Department of Biological Sciences, University of Calgary, Calgary, Alberta T2N 1N4

Abstract

Published data on mean annual epilimnetic total N (TN) and P (TP) were analyzed to find how TN : TP varies with lake trophic status. TN : TP is high in oligotrophic lakes and very low in eutrophic lakes, declining in a curvilinear fashion with increased TP. Comparison of this trend with published N : P in lake nutrient sources suggests that TN : TP reflects the source of nutrients: the ratio is high in oligotrophic lakes because they receive their N and P from natural, undisturbed watersheds which export much less P than N; mesotrophic and eutrophic lakes receive various mixtures of nutrient sources that have lower average N : P; and very eutrophic lakes have N : P that correspond very nearly to the N : P of sewage. Two inflection points were identified in the TN : TP relationship (~20 and ~100 μg TP liter^{-1}) the first probably reflecting the large difference between TN : TP in nutrient export from undisturbed terrestrial ecosystems and that of meso- and eutrophic sources such as urban and pasture land runoff and sewage, and the second probably reflecting increased rates of denitrification in eutrophic lakes. Analysis of published manipulation experiments shows that N limitation is not only significantly more frequent in lakes of low ambient TN : TP (TN : TP mass ratio $\leq$ 14) but is also significantly more frequent in lakes with TP $>$ 30 μg liter^{-1}.

Nitrogen and phosphorus are respectively the fourth and sixteenth most abundant elements in our solar system. They are present in a N : P mass ratio estimated between 192 and 660 (Cameron 1970). In contrast, the earth's crustal rocks are relatively poor in N, resulting in N : P that only varies between 0.01 and 0.8 by mass (Vinogradov 1962). The relative abundance of N and P found suspended or dissolved in lakes has been the subject of much discussion lately (e.g. Drenner et al. 1990; Molot and Dillon 1991). Various combinations of dissolution, concentration, sedimentation, fixation, and biological transformation result in N : P mass ratios in lakes varying between ~200 (e.g. Stockner and Shortreed 1985) and <1 (e.g. Prepas and Trew 1983). The relative abundance of N and P in lake water has been suggested to have both a quantitative (McCauley et al. 1989) and qualitative (Smith 1983, 1986) effect on phytoplankton communities.

One means of discerning the mechanisms yielding the widely variable N : P ratios found in lakes is to examine the form of the relationship of total N (TN) to total P (TP) in the pelagic zone of a variety of the world's lakes. Because lakes rich in P are also often rich in N (Sakamoto 1966), there is a positive correlation between the TN and TP concentrations of lakes. If the slope of this relationship is constant then N : P might not be related to lake trophic status. If, on the other hand, nutrient sources of oligotrophic and eutrophic lakes have differing N : P ratios (Ahl 1979), or mechanisms of loss of N and P from the pelagic zone differ markedly among lakes of differing trophic status, then oligotrophic and eutrophic lakes may have divergent N : P ratios. That some limnologists believe that N : P ratios and trophic status are not closely correlated is suggested by the manipulation of N : P without

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